Working Title: Tackling Concussion in Professional Rugby Union: A Case-Control Study of Tackle-Based Risk Factors and Recommendations for Primary Prevention.

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ABSTRACT

Background/Aim: Concussion, the most common injury in professional Rugby Union, occurs most commonly during the tackle. Thus, we investigated the association between tackle characteristics and concussion.

Methods: 182 video clips of tackles leading to clinically diagnosed concussion and 4,619 tackles that did not, were coded across three professional Rugby Union competitions. A variable selection process was undertaken to identify the most important variables for interpretation. A multivariate generalized linear model was used to model the association between retained variables and concussion risk. Magnitude-based inferences provided an interpretation of the real-world relevance of the outcomes.

Results: The 4 retained variables were; accelerating player, tackler speed, head contact type and tackle type. Overall, 70% of concussions occurred to the tackler and 30% to the ball carrier. There was a higher risk of concussion if the tackler accelerated into the tackle (OR: 2.49 95%CI 1.70-3.64) or the tackler was moving at high speed (OR: 2.64 95%CI 1.92-3.63). Head contact with the opposing player's head (OR 39.9 95%CI 22.2-71.1) resulted in a substantially greater risk of concussion compared to all other head contact locations.

Conclusions: Interventions that reduce the speed and acceleration of the tackler and reduce exposure to head to head contact would likely reduce concussion risk in professional Rugby Union.

WHAT ARE THE NEW FINDINGS?

- The majority of tackle-related concussions are sustained by the tackler
- Concussion risk was greater if the tackler accelerated into the tackle, or moved at high speed.
- Concussion risk was greater when there was head contact with the opposing player's head or knee, or head contact with the ground.

HOW MIGHT IT IMPACT ON PRACTICE IN THE FUTURE?

- This paper provides evidence and direction for national and international governing bodies to explore coaching and rule changes to methods for reducing the speed and acceleration of the tackler and for reducing the occurrence of head to head contact

INTRODUCTION

Rugby Union is a high-intensity collision sport with around 450 contact events per professional match, of which approximately 200 are tackles (1). Overall, concussions have been shown to account for almost one quarter of all reported time-loss match injuries during a professional season (2). This high frequency of occurrence in the professional game clearly makes the primary prevention of the injury a key priority for the sport.

Rugby Union has introduced a significant number of concussion initiatives including Law changes to support an off-field head injury assessment, the introduction of an operational definition of concussion (4) and mandatory stakeholder concussion education. These and other initiatives are thought to be key factors for the year-on-year increase in the reported incidence rate of match concussion within the English professional game over the period 2009 to 2016 (2). Although much has been done to improve the awareness, identification and management of concussion in rugby, there has been little progress regarding primary prevention of the injury (5).

The tackle is the most injurious match event in professional Rugby Union (1) with high speeds, high tackle height, and front on tackles increasing the risk of injury within the tackle (6-8). The majority of concussions occur in the tackle (3) making it a focus for concussion prevention. However, the tackle characteristics associated with concussion in professional Rugby Union are not understood. In one recent study of 52 head impacts, tackler head placement and high-speed tackles were significant risk factors for head impact (9). However, whether the player was subsequently diagnosed with concussion was unknown. To our knowledge, no large-scale video analysis study investigating tackle specific risk factors of time-loss concussion in Rugby Union exists. Thus, we investigated the association between tackle characteristics and clinically diagnosed concussion to inform future game-wide injury prevention initiatives.

METHODS

Participants

This case-control study was conducted in a population of 2,029 first team male professional Rugby Players competing in three major professional Rugby Union competitions (The English Premiership, The Pro 12 and The Rugby World Cup). Data were collected over 3 seasons (2013/14, 2014/15 and 2015/16). Written informed consent was obtained from each participant and the Research Ethics Approval Committee for Health at the University of Bath approved the study.

Procedures

A single experienced game analyst coded tackle events that led to a clinically diagnosed concussion (hereafter known as concussion), using a pre-defined coding matrix on a bespoke analysis platform (Fair Play Pty Ltd, Australia). For the purpose of this study, and in agreement with a previous study (6), the definition of a tackle used for the study was based on World Rugby law (10) and was defined as 'any event where one or more tacklers attempted to stop or impede the ball carrier whether or not the ball carrier was brought to ground.'

Over the period of data collection, the head injury assessment (HIA) process was in place in order to aid both clinical decision-making (in-game) and subsequent diagnosis (post-game) of concussion. This three-point in time assessment process (4) was consistent over the study period and was the operational process that informed the clinical diagnosis of concussion made by the team doctors in this study. .Concussion cases that occurred in domestic competition were reported in each union's respective, well-established injury surveillance system. Similarly, concussions that occurred during the Rugby World Cup (RWC) 2015 were reported via the RWC injury surveillance system. All three surveillance systems utilised consistent definitions and were aligned with the consensus statement for the reporting of injuries in Rugby Union (11). These systems reported detailed injury information (such as injury date, competition, playing position, injury event and time of injury) to help identify the specific match event that led to the player being diagnosed with concussion. Any concussions reported as delayed or evolving were not included in the study as they could not be directly associated to a specific match event.

The coding matrix applied to each video clip comprised fifteen categorical variables, the majority of which described characteristics of the tackle but also included pre-tackle characteristics (such as player position and preceding event). The coding matrix was developed from the templates utilised in previous studies investigating tackle injuries in professional Rugby Union (6-8). The variables reported in this study were; identification of the accelerating player, tackler speed, contact type and tackle type. The inclusion of these variables specifically was determined by the modelled degree of importance of each variable (see data analysis section below).

In addition, a control group of 4,619 tackles that did not result in a concussion were coded from 28 matches in representative professional rugby competitions. These were coded by the same analyst to calculate frequency of occurrence in normal match play and to help quantify the value of any potential recommendations for the game on concussion risk. Video clips were excluded if; a) the quality of the video footage did not allow the match event to be clearly observed or b) the footage was of insufficient quality to apply the coding template to the tackle.

Data Analysis

All estimations were made using *R* (Version 3.3.1, R Foundation for Statistical Computing, Vienna, Austria). Firstly, in order to establish the importance of each coded variable in predicting the risk of concussion in the tackle, a machine learning model was used to identify the variables that, when removed from the model, were associated with the largest increase in concussion prediction error (i.e. the variables that were associated with the biggest decrease in predictive accuracy when they were not included). This was performed using the variable importance feature within the *randomForest* package (12), with an increase in mean square error of 20% set as a threshold for retaining variables (13). This then also allowed us to select the most parsimonious model for further statistical analysis (14). Subsequently, a multivariate generalized linear model (GLM), with binomial distribution and logit link, was used to model the associations between the different scenarios within each retained variable and risk of concussion. Correlation coefficients between the variables, alongside Variance Inflation Factors (VIF), were used to detect multicolinearity between the predictor variables. A VIF of ≥10 was deemed indicative of substantial multicolinearity (15). The most frequently occurring category within each variable was used as the reference condition. The resultant odds ratios were plotted against the overall frequency of each tackle characteristic, to allow interpretation of both the risk associated with the given tackle characteristic and the regularity with which it occurs (16). The associated 95% confidence intervals were used to represent the likely range of the true value.

Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcomes (17). The smallest important increase in injury risk was a relative risk of 1.11, and the smallest important decrease in risk was 0.90 (18). Effects were classified as unclear if the percentage likelihood that the true effect crossed both positive and negative smallest worthwhile effect thresholds were both greater than 5%.. Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following scale: <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (19).

RESULTS

247 concussions where the player was permanently removed from play were identified through interrogation of the three primary injury surveillance systems. 65 of these were excluded due to

either a) insufficient video quality or b) not being able to identify the causal event in the video. This left 182 concussions that were sustained in 171 matches available for further analysis in this study. Of the 182 concussions, 70% of concussions were sustained to the tackler and 30% to the ball carrier.

Within the statistical model, the most important variables (ranked from highest to lowest) for predicting concussion outcome were; accelerating player (percentage increase in Mean Square Error [MSE] when the variable was removed: 86%), tackler speed (78%), head contact type (31%) and tackle type (25%; figure 1). Within the accelerating player variable, there was a most likely higher risk of concussion if the tackler was accelerating into the tackle (OR: 2.49 95% CI 1.70-3.64) and a likely higher risk when both players accelerate into the tackle (OR: 1.44 95% CI 1.01-2.04) when compared with an accelerating ball carrier (figure 2). Similarly, when the tackler was moving at high speed, there was a most likely higher risk of concussion (OR: 2.64 95% CI 1.92-3.63) when compared to the reference scenario of low speed (figure 3).

Head contact with the opposing player's head (OR 39.9 95% CI 22.2-71.1), ground (OR 21.8 95% CI 7.8-61.3), and knee (OR 20.3 95% CI 10.2-40.3) had substantially greater risk of concussion compared to all other locations. However, these scenarios occurred infrequently compared to more common impact types such as head to trunk, lower limb and pelvis impacts (figure 4). All sub-variables analysed were more likely to result in concussion than the most common and lowest risk scenario of head to trunk contact (figure 4). All illegal tackle types (referee determined high tackle, tip tackle and tackle in the air) were associated with the highest risks of concussion, but all were rare events (these tackle types occur at a frequency of ≤ 2 per 1000 tackles). High tackles were 36.5 times more likely (OR 36.5 95% CI 24.7-53.9) to result in a concussion when compared with passive shoulder tackles (figure 5).

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DISCUSSION

In our study of tackle characteristics and concussion 70% of concussions associated with the tackle were sustained to the tackler and 30% to the ball carrier. In order to establish the importance of each coded variable in predicting the risk of concussion in the tackle, We pioneered using a machine learning model to identify the variables that, when removed from the model, were associated with the largest increase in concussion prediction error. The (i) accelerating player, (ii)tackler speed, (iii) head contact type and (iv) tackle type were identified as the four tackle characteristics that statistically represented the greatest likelihood for modifying the risk of concussion within a tackle. Accelerating player and tackler speed variables had the largest influence on whether a concussion occurred in the tackle.

Next, a multivariate generalized linear model was used to model the associations between the different scenarios within each retained variable and the likelihood of concussion. Specifically, the likelihood of concussion increased significantly if a) the tackler or both players were accelerating rather than the ball carrier accelerating; b) the tackler was at high speed rather than at low speed or c) if the head made contact with the opposing player's head, knee, or the ground rather than the most common location (the trunk). Furthermore, high tackles were 36.5 times more likely to result in a concussion compared with passive shoulder tackles. Of the variables analysed, the sub-variables associated with the highest risk of concussion were never the most frequent, suggesting that the current structure and governance of the game already goes some way to reducing player exposure to the highest risk tackle characteristics.

Concussion Prevention Opportunities

To successfully reduce the risk of concussion in professional Rugby Union, the theoretical options for risk mitigation need to be considered against the real-world landscape (20). We identified the tackle characteristics that were most associated with the risk of concussion and we noted their frequency. The frequency of each event is important as a moderate risk; high frequency event may cause more concussions than a high risk, low frequency event. That is not to say, for example, that reducing the frequency of high risk but relatively uncommon events such as referee determined high tackles should be overlooked. This should still be a target to reduce concussion risk but it may not yield the same real-world benefit as a risk reduction strategy focused on reducing the frequency of a more common match scenario.

The most effective, albeit extreme, method for preventing concussion would be to eliminate exposure by removing the tackle from the game (21). However, removing one of the sports integral game events would change Rugby Union beyond recognition (21, 22) and is therefore unlikely to be a practicable option at the professional level. A more considered approach would be to suggest modifications to, or the reinforcement of existing law to drive changes in player behaviour (5). This is a model that has been credited with significant success in other areas of the game such as the scrum (23), and in other contact sports such as ice hockey (24). In addition, initiatives that focus on addressing the technical aspects of the tackle via coach and player education could also be beneficial in reducing concussion risk if structured, translated and implemented appropriately (20). The potential of this approach is discussed in more detail later.

Tackler Speed and Acceleration

The most compelling finding from this study was the association between tackler movement (both acceleration and speed) and the risk of concussion. Previous studies have also suggested that the velocity dynamics of the tackle increase the risk of injury (1, 8) but we have specifically identified an association between the tackler's movement profile and concussion risk. The most commonly observed game situation that led to a high speed and/or accelerating tackler was where the tackling player 'rushed' up out of the defensive line to make an effective tackle and specifically attempted to try and stop the ball carrier making the pass.

Limiting the speed of the tackler in the performance focussed professional game will likely prove a complex challenge, but based on the findings of this study, will likely afford the biggest reduction in concussion risk (but not necessarily incidence given the low frequency of occurrence of these events). When the tackler was travelling at high speed, more injuries were sustained by backs than forwards *(data not shown).* Thus, one strategy for consideration might be to reduce the space between 'backlines' at set piece plays to reduce subsequent energy transfer (8) in the tackle. The potential negative consequence of this may however be that tacklers accelerate into tackles more often to attain physical dominance in the contact event. Presently, that situation is relatively rare, but an increase in frequency of tacklers accelerating would in fact increase concussion risk, as we have shown in the results of this study.

Tackler Vs. Ball Carrier Risk

In agreement with previous research conducted in elite Rugby Union (9), the majority of concussions in this study were sustained to the tackler (70%). Moreover, recent data from the English Premiership showed that 46% of all injuries sustained to the tackler during a competitive season were concussion (2), further highlighting the need to focus on reducing the number of concussions sustained specifically by the tackler.

The fact that there is a difference in the risk of concussion between the tackler and ball carrier is unsurprising given that their direction and points of application of energy in the tackle differ (8). The existing tackle law limits the height of the tackler's contact on the ball carrier to the line of the ball carrier's shoulders, thereby reducing the risk of contact with the head of the ball carrier. Consistent application of this law with sanctions for non-compliance by the tackler is critical in minimising the risk of concussion to the ball carrier. However, it is conceivable that further modification (lowering) of the permitted height of the tackler's contact with the ball carrier may reduce the risk of head injury to both players, with relatively greater reductions in risk to the ball carrier (7). It is important to consider that the tackler, who is at greatest risk of head injury even for higher impact types such as head to head contact, may also be protected to some extent by the lowering of tackle height, with the potential to reduce the absolute number of concussions by a meaningful amount, although the magnitude of this relationship remains unknown.

It is therefore probable that to directly increase the safety of the tackler, the most efficacious approach would likely be to focus on creating technical and/or tactical modifications through coach and player awareness and education. A recent study in elite youth players demonstrated an association between tackle technique and concussion (25) and although not formally studied, cases of poor tackle technique leading to injury have been observed in the professional game (8). In addition, a biomechanical analysis of fifteen Rugby Union players suggested that tackles executed on the non-dominant side were less compliant with current coaching recommendations regarding head position (26). A large case-control study in the professional game would likely provide insight into the specific areas of focus for such player safety initiatives in the future. It is acknowledged that it remains unknown as to whether this type of intervention would be more or less effective in the professional game compared with the amateur game, and further research is required to guide the judicious application of such an intervention.

Head Contact

Referee determined high tackles were 36.5 times more likely to result in a concussion when compared to the most common tackle type (passive shoulder) and in addition, head-to-head contacts were around 40 times more likely to result in a concussion when compared to head to trunk contact. Both of these findings are in agreement with findings presented in previous studies (6-8). It is of note that these findings also support World Rugby's recent initiative of a zero-tolerance towards head contact with game-wide increased sanctions now in operation for contact with the head (27). However, whilst efforts to shift actions away from the highest risk events should be applauded, it is also important to monitor the possibility that reducing risk in one area of the game may change the risk in another (28). In this study, head-to-knee and head-to-ground contact were also high risk, with approximately a 20-fold increase in risk when compared to the most common head contact type of head to trunk. However, any intervention that replaces head-to-head impacts with any other impact type stands to reduce the incidence of concussion based on the present data. One previous study found that the all-injury risk to the tackler increased when the tackler made low tackles (8). However, it is important to note that lowering the tackle height would not necessarily increase the frequency of low tackles *per se*. As mentioned, the desired outcome would be to increase the frequency of mid-height tackles where the risk of concussion is lowest (Figure 4). Since head to trunk contact types are already the most frequently occurring, it would seem likely that any interventions designed to minimise contact with the head may increase the frequency of these tackle types. This would, as a consequence, reduce the incidence of concussion in the professional game. Due to the unpredictability of possible outcomes following any tackle-height law intervention, the continued monitoring of all injury risk using well-established injury surveillance systems is warranted. It should also be noted that the illegal tackle types (referee determined high tackle, tip tackles and tackles in the air) were the rarest events suggesting that current law is effective in deterring these behaviours.

Limitations

One limitation of this study was the reliance upon subjective interpretation for many of the tackle variables presented. In future, micro-technology could be used to quantify data such as relative speeds and thus improve the objectivity of the analysis. Separately, a number of concussions were excluded from the analysis due to poor video footage or post-match presentation. These cases, particularly those with delayed onset of symptoms, may differ from those presenting on field, and the present study is unable to examine this possibility. Whilst illegal tackle types were identified based on referee decisions in the study (high tackle, tip tackle etc.), whether the law was applied correctly in each situation (i.e., did the referee make the correct decisions at the time) remains unknown and warrants further investigation. Whilst adequately powered to detect subtle differences in concussion risk between variables in our multivariate model, a number of these variables were subject to sparse-data bias and should be interpreted with caution (29; supplementary data file 1). In addition, this study was underpowered for the analysis of sub-variable interactions and to consider the effect of different tackle characteristics on injury severity. Given the likely differences in physical and tactical game characteristics at different levels of the rugby, these findings are unlikely to be generalisable to non-professional cohorts.

Summary and Conclusions

Tackles that result in head-to-head contact have the high risk of concussion. Change, reinforcement and/or modification of existing tackle law particularly regarding the height of the tackle may reduce direct contact with the head of the ball carrier. Furthermore, identifying ways of reducing the speed and acceleration of the tackler whilst they make effective tackles must also explored. We emphasise that rule changes bring with them unknown impact upon the risk of other injury types.

Competing Interests: MC, SK are employed by the Rugby Football Union. MR, BH and RT are employed by World Rugby. CR and PM are employed by the Welsh Rugby Union and have previously received research funding from World Rugby. SW and KS are employed by the University of Bath and have previously received research funding from the Rugby Football Union.

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